THE NOISE EXPOSURES OF MOBILE MACHINE OPERATORS IN U.S. SURFACE COAL MINES AND NOISE CONTROL TECHNIQUES

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ABSTRACT

The reduction of the noise exposure of operators of mobile surface mine equipment has been a primary objective of the Bureau of Mines. Approximately 25,000 mobile equipment operators in U.S. surface coal mines (45 pct of the operators) are overexposed to noise. These mobile machines include bulldozers, front-end loaders, haulers, shovels, draglines, trucks, scrapers, drills, and motor graders. Bull-dozers and front-end loaders cause about two-thirds of the noise overexposures. The most cost-effective operator noise exposure control was determined to be acoustical cabs.

INTRODUCTION

Many mobile machines used in U.S. surface coal mines produce noise levels higher than those permitted by the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) and the Federal Mine Safety and Health Amendments Act of 1977 (Public Law 95-164). Recognizing this problem, the Bureau sponsored projects to identify and control noise levels from these machines. The first project was a census of the types and number of mobile machines in surface coal mines (1).[3] This project involved measurements of noise generated by mobile machines and an estimate of the total operator overexposure (2). Cost-effective noise control techniques were then developed and proven on bulldozers and front-end loaders (3-6).

MACHINE CENSUS

Results from a combination of questionnaires and extrapolations show there were approximately 38,500 mobile machines in use at U.S. surface coal mines in 1977. Extrapolations were required because although a questionnaire was mailed to every mine address on Mine Safety and Health Administration (MSHA) and Bureau lists, not all mines responded. Two methods of extrapolation were used independently; one was based on production and the other was based on survey response rate. Both methods yielded comparable results (1).

Table 1, which lists the machines in order of the number in use, shows that two types dominate. Heavy track dozers (≥150 hp) are the most numerous, accounting for more than 27 pct of all machines. They are followed by heavy wheel front-end loaders, which account for more than 16 pct. Together these two types account for over 43 pct of all machines used in surface coal mines. All types of dozers combined form nearly 30 pct of the total population, and all types of loaders form nearly 20 pct, together accounting for nearly one-half of all machines used in surface coal mines.

Table 2 lists the predominant manufacturers of each major machine category, the predominant models in use, and the percentage of these models in each category. For example, the table shows that

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[3] Underlined numbers in parentheses refer to items in the list of references preceding the appendix to this paper.

TABLE 1. - Ranking of machine types on basis of numbers in use

Rank	Percent-- Of total	Percent-- Cumulative	Machine	Rank	Percent-- Of total	Percent-- Cumulative	Machine
1..	27.3	27.3	Dozer, track, $\geq$150 hp.	10..	3.0	90.9	Scraper.
2..	16.4	43.7	Loader, wheel, $\geq$150 hp.	11..	2.5	93.4	Loader, wheel, $<$150 hp.
3..	14.6	58.3	Hauler.	12..	1.7	95.1	Dozer, track, $<$150 hp.
4..	7.6	65.9	Truck, highway.	13..	1.3	96.4	Shovel and dragline, electric, $<$30 yd^3.
5..	7.5	73.4	Shovel and dragline, internal combustion power.	14..	1.0	97.4	Shovel and dragline, electric $\geq$30 yd^3.
6..	4.0	77.4	Scraper, tandem.	15..	.8	98.2	Auger, coal, highwall.
7..	3.8	81.2	Motor grader.	16..	.8	99	Loader, track.
8..	3.4	84.6	Drill, blasthole, without cab.	17..	.5	99.5	Dozer, wheel.
9..	3.3	87.9	Drill, blasthole, with cab.	18..	.3	99.8	Drill, coring, truck-mounted.

TABLE 2. - Major machine models in use in U.S. surface coal mines, by portion of machine type population, percent

Machine type and manufacturer	Model		Machine type and manufacturer	Model		Machine type and manufacturer	Model	
Dozer:			Shovel--Con.			Scraper:		
Caterpillar...	D9	47	Northwest.....	800	4	Caterpillar...	637	18
	D8	17		All	9		631	12
	All	71	Lima..........	All	8		657	7
International.	TD25	11	Manitowoc.....	3500	4		All	55
	All	12		All	8	Terex.........	T524	16
Allis-Chalmers	All	7	Dragline:				All	25
Loader:			Manitowoc.....	4600	13	Euclid........	All	5
Caterpillar...	988	18		4500	8	Blasthole drill:		
	992	19		All	25	Gardner-Denver	RDC16	10
	All	46	Bucyrus-Erie..	88B	9		All	15
Hough.........	All	13		All	25	Bucyrus-Erie..	50R	5
Michigan......	All	13	Lima..........	2400	13		All	14
International.	All	6		All	18	Chicago		
Hauler:			Marion........	All	12	Pneumatic....	650	9
Euclid........	All	32	Page..........	All	9		All	13
Caterpillar...	773	10	Highway truck:			Robbins.......	All	13
	All	18	Ford..........	F100	4	Ingersoll-Rand	All	11
Wabco.........	All	12		F600	4	Grader:		
International.	All	10		All	28	Caterpillar...	12	28
Mack..........	All	8	Mack..........	600	4		16	22
Dart..........	All	5		685	3		14	16
Shovel:				All	18		All	72
Bucyrus-Erie..	All	26	General Motors	All	12	Galion........	All	12
Marion........	All	19	Chevrolet.....	All	11			
Lorain........	All	11	International.	All	10			
			White.........	All	8			

NOTE.--All refers to all of the manufacturer's models in use.

Caterpillar dominates the dozer category: Caterpillar manufactures 71 pct of all dozers used in surface coal mines, 47 pct of which are Caterpillar model D9. Caterpillar also manufactures 46 pct of all front-end loaders used in surface coal mines, 18 pct of which are Caterpillar model 988.

An obvious first step in reducing noise exposure is the use of operator cabs. Table 3 gives the percentages of machines that have cabs, the size of the mine in which the machine is operated, and whether the cab has any form of noise control (acoustical) treatment. As the table shows, 70 pct of all machines have cabs, nearly one-half of these machines with cabs have some kind of acoustical treatment, and there are more cabs in large mines than in small mines. In addition, there are more acoustically treated cabs on newer machines than on older equipment; acoustically treated cabs came into significant use between 1969 and 1972.

Mobile Equipment Noise and Operator Exposure

A major objective of the research was the calculation of the noise exposure of operators of various machines (see reference 2 for detailed discussion). For this calculation, independent estimates were made of the average working noise level and the time of operation (see appendix to this paper). The average working noise level was defined as that constant noise level that, if present during the entire work cycle, would result in the same noise exposure, or dose, resulting from fluctuating noise levels that actually occur. Computation of the average working noise level requires the typical work cycle to be divided into a number of events, each of which can be defined in terms of a typical noise level and percentage of the work cycle; for example, for a dozer, the typical work cycle consists of dozing, transporting, and backing. It is equivalent to the level read from a noise dosimeter measuring noise over one work cycle.

TABLE 3. - Machines with cabs, by mine size, percent

Machine	Any cab			Acoustical cab		
	Large[1]	Small[2]	All	Large[1]	Small[2]	All
Dozer, track, ≥150 hp	58	57	57	35	29	32
Loader, wheel, ≥150 hp	67	70	62	44	44	44
Hauler	25	86	93	57	34	53
Truck, highway	97	92	96	5	10	7
Shovel and dragline, internal combustion power	85	83	78	33	19	26
Scraper, tandem	62	52	60	30	15	26
Motor grader	60	64	61	32	30	32
Drill, blasthole	50	50	50	22	18	22
Scraper	53	27	47	24	8	21
Loader, wheel, <150 hp	61	56	59	41	26	35
Shovel and dragline, electric:						
<30 yd^3	91	80	89	59	25	54
≥30 yd^3	89	60	86	62	30	58
Dozer, track, 150 hp	63	45	57	36	29	28
Auger, coal, highwall	18	18	18	3	2	2
Loader, track	65	41	50	27	15	20
Dozer, wheel	83	50	81	56	50	55
Drill, coring, truck mounted	46	50	47	0	17	3
Total machine population	72	60	70	37	30	34

[1]≥100,000-t/yr production. [2]<100,000-t/yr production.

Data on machinery noise, work cycles, machine usage durations, and shift lengths were collected during visits to nine mines that included both large and small operations, located in the Appalachian, Midwestern, and Western regions. Data on the noise and work cycles of over 80 individual machines were obtained by direct measurement, and these data were supplemented by information extracted from interviews with mine personnel. Additional data were gathered from study reports made available by some mines, from the literature, and from a sample of records submitted by mine operators to one of the MSHA district offices.

Operator exposures were evaluated on the basis of the most reliable data available. Where possible, noise data measured in this program were used. For machine types for which information was inadequate, estimates were based on data in the literature of the MSHA records. Daily exposure durations were taken directly from the MSHA data.

Table 4 shows the mean values and standard deviations of the average working noise levels of the operators of various machines, daily operator exposure durations, and the probabilities of operator over-exposure. A distinction is made to the extent allowed by available data between machines with no cabs, conventional cabs, and acoustical cabs.

The overexposure probabilities indicate the fractions of the total operator population that suffer overexposure according to the given criteria. These probabilities provide no information about how often (what fraction of the time) the exposure of the operator of a given machine exceeds the permissible limit. These overexposure probabilities are given for two criteria. The first criterion is a regulation specified in the Coal Mine Health and Safety Act of 1969, which permits exposure to 90 dBA for a maximum of 8 h per day and prescribes a reduction by a factor of 2 in the permissible daily exposure duration time for each 5-dBA noise level increment above 90 dBA. The second, more stringent, criterion permits exposure to 85 dBA for a maximum of 8 h per day and again prescribes an exposure duration time reduction by a factor of 2 for each 5-dBA increment above 85 dBA.

As shown in table 4, operators of heavy track dozers without cabs are exposed to mean working noise levels of 103 dBA for a mean of 6 h per day. The last two columns of the table show that 96 pct of the opera-tors of dozers without cabs in surface coal mines are overexposed to noise, according to the current Federal regulations. If the 5-dBA reduced threshold criterion is adopted, 99 pct of the operators are overexposed. The procedure for calculating the overexposure probability is given in reference 2.

Table 4 also shows that when cabs--particularly cabs with noise control treatments--are used on any type of machine, they decrease both working noise levels and the probability of overexposure.

For each of the various types of machines used in U.S. surface coal mines, table 5 shows the total number of machines in use (based on projections developed from the census data), the average number of people operating each machine per day (based on the average number of daily shifts the machines are in use, according to the machine census), and the number of operators in all U.S. surface coal mines who may be expected to be overexposed (according to both the current criterion and the more stringent criterion). The table also shows the percentages of the total number of operators (approximately 56,200) who suffer overexposure.

This table gives two important statistics. According to the present criterion, over 25,000 operators, or nearly 45 pct of all mobile machine operators in U.S. surface coal mines, are overexposed to noise. With the more stringent criterion, the number of operators overexposed to noise increases to over 37,000, or more than 66 pct of the entire operator population.

TABLE 4. - Noise exposure of machine operators

(Average working noise level based on reference 2 and verified mine data, except as otherwise noted; values are rounded to nearest 0.5 dBA).

Machine	Cab[1]	Average working noise level, dBA		Daily exposure duration, h[2]		Criterion	
		Mean	Standard deviation[3]	Mean	Standard deviation[3]	Present[4]	5-dBA-more stringent[5]
Dozer, track:							
>150 hp	N	103	1.5			96	99
	C	98.5	3.0	6.0	2.8	88	96
	A	92.6	4.5			49	80
<150 hp	T	[L]94	[L]3.5	5.7	3.5	57	83
Dozer, wheel	N	[e]96	[e]5.0			55	81
	C	96.5	2.0	4.2	2.0	65	90
	A	92	6.0			32	60
Loader, wheel:							
>150 hp	N	94.5	1.5			74	93
	C	93.5	5.0	6.3	3.0	56	82
	A	84.6	4.5			5.9	29
<150 hp	T	[I]97	[I,e]3.0	5.9	3.2	79	93
Loader, track	T	[L]91.5	[L,e]4.0	5.5	3.8	37	69
Hauler	T	88.5	4.5	6.1	2.5	23	57
Truck, highway	T	[e]85	[e]5.0	3.6	2.0	2.6	14
Scraper:							
Tandem	N	[e]92	[e]7.0			44	69
	C	91.5	7.0	5.6	2.3	41	67
	A	85	.5			0	14
Single	N	[e]96	[e]5.0			69	89
	C	95.5	3.5	5.8	2.6	71	92
	A	91	[e]5.0			37	69
Motor grader	N	[e]96	[e]5.0			62	84
	C	[I]95.8	[I]4.0	5.1	3.1	64	86
	A	86.5	5.0			11	35
Shovel and dragline:							
Electric:							
>30 yd³	T	77.5	6.5	5.3	1.5	1.2	6.2
<30 yd³	T	86	4.0	5.8	2.3	6.7	35
Internal combustion power	T	91	6.5	5.9	3.7	38	64
Drill:							
Blasthole	N	90	2.0	5.6	2.5	20	70
	C	85	5.0	5.1	2.7	7.2	27
	A	83	3.0	5.1	2.7	.2	7.8
Coring	T	[e]87	[e]5.0	5.4	2.8	14	40
Auger	T	[e,M]95	[e]5.0	4.1	2.0	48	76

[e]Estimated. [I]Includes literature data. [L]From literature. [M]Includes MSHA data.
[1]A, acoustical cab; C, nonacoustical cab; N, no cab; T, all conditions.
[2]Rounded to nearest 0.1 h.
[3]About 70 pct of all values may be expected to fall within 1 standard deviation below and above the mean.
[4]85 dBA permissible for 8 h daily; a reduction factor of 2 in the permissible daily exposure for each 5-dBA increase above 90 dBA.
[5]85 dBA permissible for 8 h daily; a reduction factor of 2 in the permissible daily exposure for each 5-dBA increase above 85 dBA.

TABLE 5. - Projected number of machines and overexposed operators in U.S. surface coal mines (2)

(Projected total number of operators--56,226)

Machine	Cab[1]	Number of machines[2]	Operators per machine per day,[2] average	Overexposed operators: Present criterion[3] No.	Overexposed operators: Present criterion[3] pct	Overexposed operators: 5-dBA-more-stringent criterion[4] No.	Overexposed operators: 5-dBA-more-stringent criterion[4] pct
Dozer, track:							
≥150 hp	N	4,551	1.56	6,816	12.1	7,028	12.6
	C	2,648		3,635	6.5	3,966	7.1
	A	3,447		2,635	4.7	4,302	7.7
<150 hp	T	584	1.34	446	.8	649	1.2
Dozer, wheel	N	24	1.92	25	<.1	37	.1
	C	32		40	.1	55	.1
	A	71		44	.1	82	.1
Loader, wheel:							
≥150 hp	N	2,149	1.36	2,163	3.8	2,718	4.8
	C	1,661		1,265	2.2	1,852	3.3
	A	2,991		240	.4	1,179	2.1
<150 hp	T	1,033	1.30	1,061	1.9	1,249	2.2
Loader, track	T	411	1.13	172	.3	320	.6
Hauler	T	5,620	1.52	1,965	3.5	4,869	8.7
Truck, highway	T	2,939	1.25	95	.2	514	.9
Scraper:							
Tandem	N	462	1.47	299	.5	469	.8
	C	393		237	.4	387	.7
	A	310		0	<.1	64	.1
Single	N	486	1.33	446	.8	575	1.0
	C	252		238	.4	308	.5
	A	197		97	.2	181	.3
Motor grader	N	549	1.19	405	.7	549	1.0
	C	411		313	.6	421	.7
	A	450		59	.1	187	.3
Shovel and dragline:							
Electric:							
≥30 yd^3	T	234	3.14	9	<.1	46	.1
<30 yd^3	T	334	2.20	49	.1	257	.5
Internal combustion power	T	3,273	1.45	1,803	3.2	3,037	5.4
Drill:							
Blasthole	N	1,316	1.20	316	.6	1,105	2.0
	C	721	1.75	91	.2	341	.6
	A	558	1.75	2	<.1	76	.1
Coring	T	109	1.47	22	<.1	64	.1
Auger	T	323	1.53	237	.4	376	.7
Total or average	NAp	38,539	1.46	25,225	44.9	37,263	66.3

NAp Not applicable.
[1]A, acoustical cab; C, nonacoustical cab; N, no cab; T, all conditions.
[2]Reference 1.
[3]85 dBA permissible for 8 h daily; a reduction factor of 2 in permissible daily exposure for each 5-dBA increase above 90 dBA.
[4]85 dBA permissible for 8 h daily; a reduction factor of 2 in permissible daily exposure for each 5-dBA increase above 85 dBA.

Table 5 also shows that all types of dozers together are responsible for overexposure of over 13,600, or over 24 pct of all surface mine operators; that is, dozers contribute more than 50 pct of all noise overexposures. Loaders, in turn, overexpose more than 4,900 operators, or 8.6 pct of all surface mine operators, and they account for slightly less than 19 pct of all noise overexposures.

The next most significant categories lag far behind dozers and loaders. They are haulers, which overexpose nearly 2,000 operators (3.5 pct of all operators, 8 pct of all overexposed operators) and diesel-powered shovels and draglines, which overexpose about 1,800 operators (3.2 pct of all operators, 6 pct of all overexposed operators).

Two facts should be noted, because they have a bearing on the over-exposures shown in table 5. Most of the overexposure associated with haulers results from haulers being operated with open windows; haulers whose noise is measured with their windows closed rarely present a noise overexposure problem. Similarly, the data base for shovels and draglines powered by internal combustion engines is biased toward older models because newer models tend to be much quieter. As a result, the overexposures indicated for haulers and for shovels and draglines may be overestimated.

NOISE CONTROLS

The extent of operator overexposure, the types of mobile machines responsible for that overexposure, and the results of the first study, were published in a Bureau report (1). As a result of this study, the Bureau sponsored research to prove cost-effective retrofit noise control technology for surface mobile equipment. Because bulldozers and front-end loaders are responsible for approximately two-thirds of the noise overexposure problem, they were chosen as representative machines for this project. Description of this project is prefaced by a general discussion of noise control techniques--the tools of noise control.

Major Sources and Paths

In general, the noise from any one source reaches the ear via several paths, both directly, by airborne paths, and indirectly, by reflections from various surfaces. In addition, sound in the form of vibration may travel along or through structures.

In diesel-powered mining equipment, the engine is generally a major source of noise. Engine noise may come from the exhaust, the intake, and the casing (that is, the block and accessories attached to it)--as well as the cooling fan--often a significant noise source. The transmission, drive train, and hydraulic system also tend to be significant noise sources.

Noise radiated from the various sources may reach the operator by propagating through the air, directly or by reflections. In addition, vibrations produced by the engine and other mechanical components, as well as structural vibrations caused by sounds, tend to propagate along machine structures, thus causing these structures to radiate sound.

The relative importance of the various noise sources and paths differs for different machine types and models. However, one fact is basic for all machines: Just as repair of small holes in a leaking roof is useless if large holes are left open, reducing the noise of lesser sources and paths has practically no effect on a worker's exposure unless the contributions from the major sources and paths are reduced. In addition, it does not usually make sense to spend the money to quiet dominant sources and paths to the point where their contributions are far below those of the lesser sources and paths. Overquieting is both impractical and costly.

Noise Reduction of Diesel-Powered Equipment

In general, the noise exposure of an operator of a given machine may be reduced by blocking the paths of sound between the important noise sources and the miner. Usually, for both practical and economical reasons, the primary noise sources cannot be modified or replaced with quieter ones (except relatively early in the development of new machines). Generally then, the first solution to a problem of mine machine noise is blocking the noise paths, both airborne and structureborne.

Cabs generally are the most cost efficient way to obstruct the radiation of sound from such sources as engines or transmissions. The effectiveness of such an enclosure increases with the mass of its walls, and effectiveness is greater if the cab is lined with some kind of acoustically absorptive material. If a full cab installation would present problems of cooling or access, partial cabs or barriers may be used. They tend to be considerably less effective in noise reduction than full cabs because they do not provide the operator with noise attenuation from all directions, which increases the operator exposure to both direct and reflected noise. In a partial cab, the noise the operator hears is not passing through it, but traveling around it. As a result, increasing the mass of the barrier (an effective way to reduce noise heard in full cabs), usually results in little noise reduction in partial cabs.

Mufflers obstruct the propagation of sound out of pipes or ducts, primarily by reflecting some of the sound back toward the source so that the reflected pressure waves almost cancel out the outgoing waves. It is important to match engine exhaust mufflers to the engine, so that they will be effective acoustically, yet not produce excessive backpressure. Mufflers are commericially available for almost all pieces of equipment used in U.S. surface mines.

One of the most overlooked ways to reduce noise levels is machine maintenance. Table 4 shows a number of machine categories, such as highway trucks, with standard deviations of 4 dBA or more. This is a significantly large variation between the noise of one machine and another in the same category. There could be several reasons, of course, but experience has shown that a major contribution is the state of repair of the individual machine. Are the seals tight? Are all windows in place? Is the air conditioner working so the operator will not need to open the windows (letting in air and also noise)? Are the floormats in place? Proper maintenance of the machine is a must for successful noise control.

RESULTS OF RETROFIT NOISE CONTROL PROGRAM

The Bureau's surface mining noise control research program has concentrated on retrofit acoustical cab treatments for bulldozers and front-end loaders. Models of both machine types were selected for these treatments, based on their overall popularity in the surface mining industry. The retrofitted dozers and front-end loaders were field tested in surface coal mines for a period of about 1.5 yr. In general, mine operators were satisfied with the durability and effectiveness of the noise control treatments.

Detailed fabrication manuals, containing photographs and illustrations that show how the noise control treatments were installed, have been prepared for both bulldozers (4) and front-end loaders (6). Numerous Bureau-sponsored workshops were held throughout the country to provide equipment users with a closer look at the retrofit process. Most of the workshop attendees found them beneficial, and many equipment users have since applied the noise control treatments to their own bulldozers and front-end loaders.

Bulldozers

A breakdown of the 1977 bulldozer population in U.S. surface mines (table 6) shows that the Caterpillar model D9 was by far the most popular model, comprising 47 pct of the population (1). For this reason, the Bureau treated two different varieties of D9 dozers, one with only a ROPS-FOPS structure[4] and one with a complete (but not acoustical) cab. To show that retrofit noise control treatments could also be applied successfully to another manufacturer's bulldozer, an International Harvester model TD-25C machine (ROPS-FOPS only) was also treated.

TABLE 6. - Total bulldozer population by machine model, U.S. surface mines, 1977, pct

Caterpillar D9..................	47
Caterpillar D8..................	17
International Harvester TD-25....	11
All others......................	25

Although the design details of the three machines were somewhat different, the same four basic treatments were used: (1) installing a muffler on the diesel engine exhaust, (2) sealing numerous holes in the floor and dashboard of the operator's station, (3) adding sound-absorbing materials under the ROPS-FOPS structure and under the cover of the hydraulic tank, and (4) installing vibration-isolation materials between the engine and dashboard. In addition, windshields were installed on the two dozers that originally contained only ROPS-FOPS structures. These windshields were extremely important because they blocked the direct path between the diesel engine (the largest single noise source on the machines) and the dozer operators. Seals were also installed around the doors of the cab-equipped D9 dozer.

[4]ROPS, rollover protective structure; FOPS, falling object protective structure. Modifications to ROPS-FOPS must be approved and performed by qualified people. Also, flame resistant materials should be used.

Table 7 summarizes the noise reductions achieved through the dozer retrofit treatments, the cost of the acoustical materials and hardware, and the labor hours needed to install them. Note that the operator noise levels after treatment (89-94 dBA) were low enough to permit 6 to 8 h of daily operating time without violating Federal noise regulations; before treatment, only 1 to 2 h of operating time were allowed. The effects of the individual treatments on the three machines in table 7 are described.

Caterpillar D-9G With ROPS-Fops Only

Figure 1 is a photograph of the treated dozer, and figure 2 shows the seven major components of the retrofit noise control package. Diagnostic tests of the untreated dozer indicated that the windshield would be the single most effective noise control treatment, followed by the ROPS-FOPS canopy absorption and the engine exhaust muffler; therefore, these three treatments were installed first.

TABLE 7. - Summary of results of bulldozer retrofit noise control treatments

	Caterpillar D-9G		International Harvester TD-25C, ROPS-FOPS only
	ROPS-FOPS only	With cab	
Operator noise level, dBA:			
Before treatment............	105	[1]99-[2]100	102
After treatment.............	94	[2]89-[1]91	91
Noise reduction..........dBA..	11	9-11	11
1978 material costs..........	$825	$725	$912
Labor hours..................	106	88	80

[1]Cab doors open. [2]Cab doors closed.

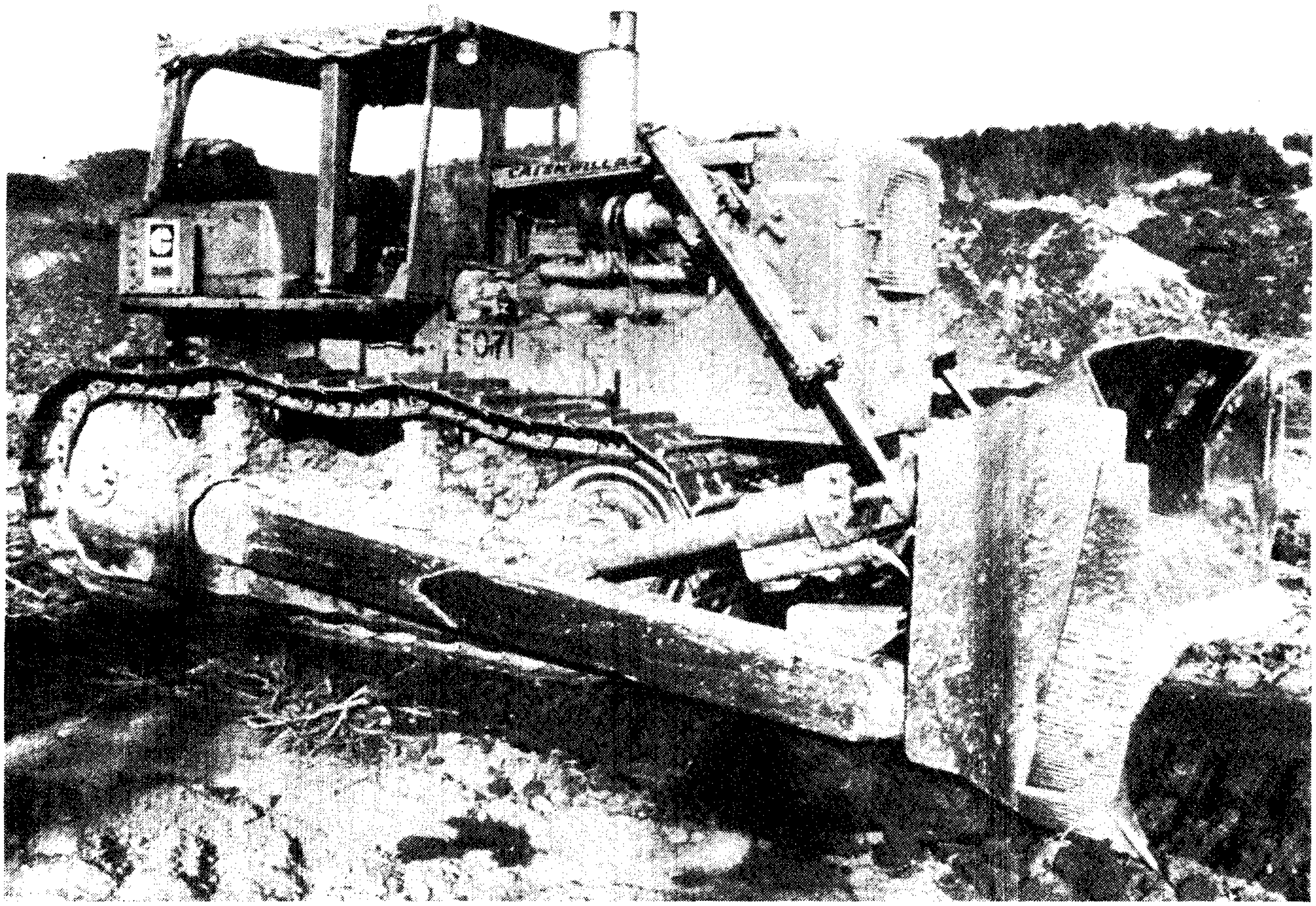

FIGURE 1. - Caterpillar D-9G bulldozer (ROPS-FOPS only) with retrofit noise control treatments.

Figure 3 shows how the operator noise level decreased as each of the seven treatments was added. The overall noise reduction was 11 dBA, but the reduction obtained through one treatment depended on the presence of the previous treatments. For example, the windshield alone would have reduced the noise by about 4 dBA, the canopy absorption alone would have reduced the noise by about 3 dBA, and the exhaust muffler alone would have reduced the noise by about 1.5 dBA. The remaining treatments would have had a negligible effect on operator noise if the windshield, canopy absorption, and muffler had not been installed; therefore, these three treatments were by far the most important components of the retrofit package. Table 8 summarizes the material costs and labor hours associated with each component of the package.

Caterpillar D-9G With Cab

Figure 4 shows the six major components of the retrofit noise control package applied to the cab-equipped D-9G dozer. This machine already had a relatively new muffler, so none was installed; however, this would ordinarily have been included in the package. Since a windshield was already a part of the cab, the simpler cab wall seal treatment replaced the windshield treatment required for the D-9G dozer with ROPS FOPS only. The interior walls of the cab were treated with the same sound-absorbing materials as the underside of the canopy. Note in table 7 that the operator noise level in the untreated cab was higher when the doors were closed than when they were open; this occurred because the untreated doors tended to rattle in their sockets when

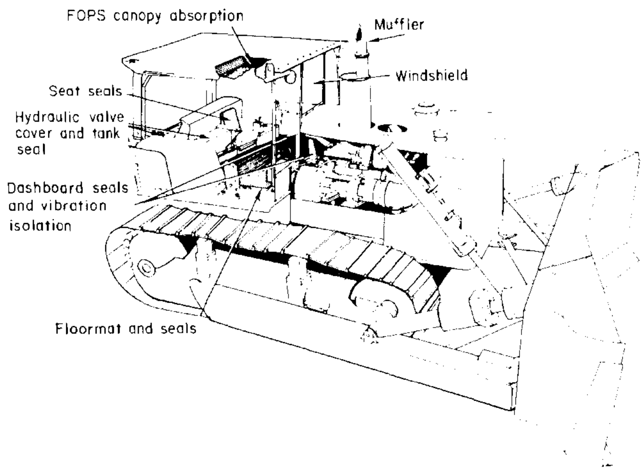

FIGURE 2. - Noise control treatments installed on Caterpillar D-9G bulldozer (ROPS-FOPS only).

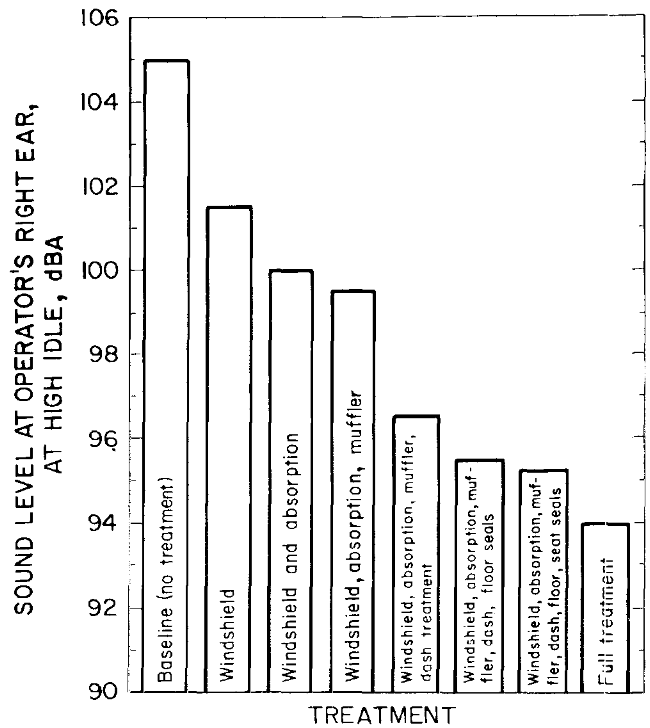

FIGURE 3. - Step-by-step noise reduction treatments of Caterpillar D-9G bulldozer.

they were closed. After the door seals were added, however, the operator noise exposure level was lower when the doors were closed.

Figure 5 shows how the operator noise level decreased as the treatments were added (11-dBA total reduction, cab doors closed). As with the D-9G dozer with ROPS-FOPS only, the noise reduction at each stage of treatment depended on the presence of the previously installed treatments. Table 9 summarizes the material costs and labor hours associated with each component of the package. Note that the cost of a muffler (although not needed on this particular machine) is also included in table 9.

TABLE 8. - Summary of material and labor costs for noise control package on Caterpillar D9G dozer with ROPS-FOPS only

Treatment	1978 material costs[2]	Labor[1] Welder	Labor[1] Mechanic	Treatment	1978 material costs[2]	Labor[1] Welder	Labor[1] Mechanic
Windshield.........	$275	29	16	Seat seals.........	$55	NAp	8
FOPS canopy absorption........	115	4	10	Hydraulic valve cover and tank seal..............	80	4	16
Exhaust muffler....	190	NAp	2	Miscellaneous items	5	2	2
Dashboard seals-vibration isolation.	25	1	4	Total.........	825	40	66
Floormat and seals.	80	NAp	8				

NAp Not applicable. [1]Estimated worker-hours. [2]Approximate.

TABLE 9. - Summary of material and labor costs for noise control package on Caterpillar D9G dozer with cab

Treatment	1978 material costs[2]	Labor[1] Welder	Labor[1] Mechanic	Treatment	1978 material costs[2]	Labor[1] Welder	Labor[1] Mechanic
FOPS canopy absorption........	$150	4	8	Dashboard seals-vibration isolation.	$25	2	4
Cab wall seals.....	75	2	22	Miscellaneous items	5	2	2
Floormat and seals.	80	2	8	Subtotal........	535	16	72
Seat and hydraulic valve seals.......	105	4	12	Muffler............	190	NAp	2
Sound absorption on cab surfaces......	95	NAp	16	Grand total...	725	16	74

NAp Not applicable. [1]Estimated worker-hours. [2]Approximate.

International Harvester TD-25C With ROPS-FOPS Only

Figure 6 shows the major components of the retrofit noise control package for the TD-25C dozer. Since the manufacturer had already installed an exhaust muffler on this machine, none was needed; however, a muffler would have to be installed if none were present. Figure 7 shows how the operator noise level decreased as the treatments were added (11-dBA total reduction), and table 10 summarizes the material costs and labor hours associated with each component of the package.

Comparison of tables 10 and 8 shows that the cost of the windshield was the biggest difference between the retrofit packages for the International Harvester TD-25C and the Caterpillar D-9G with ROPS-FOPS structures. More materials and labor were needed for the TD-25C windshield because it was larger and more difficult to fabricate, but it provided more noise reduction (5 versus 4 dBA) than the D-9G windshield. As with the

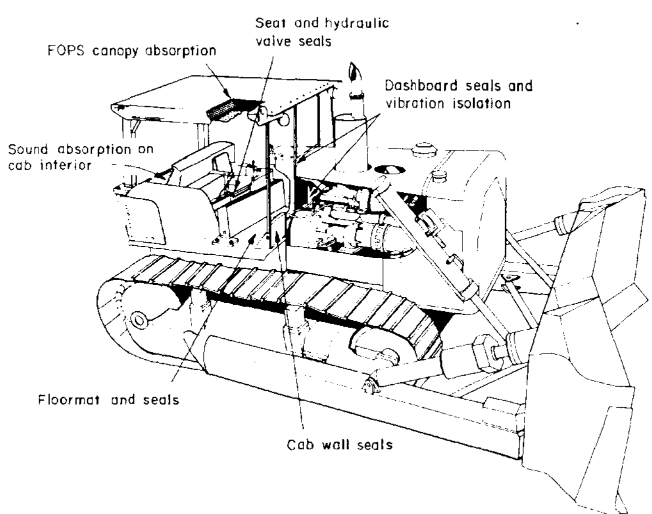

FIGURE 4. - Noise control treatments on cab-equipped Caterpillar D-9G bulldozer.

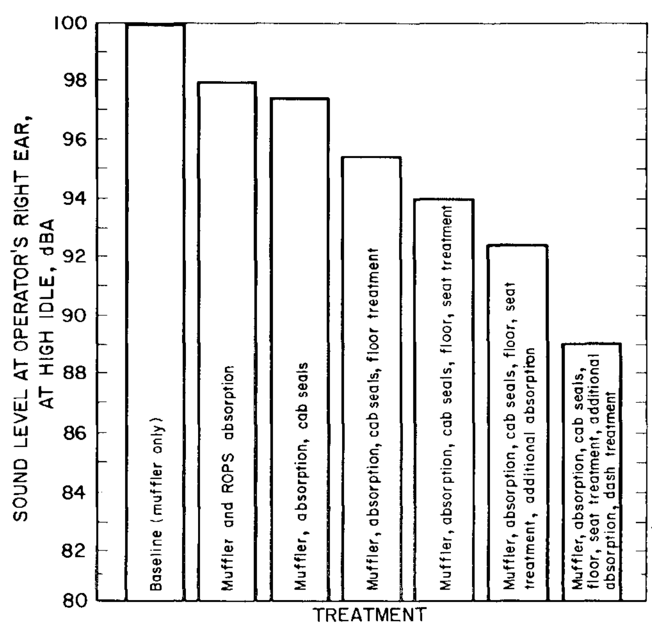

FIGURE 5. - Step-by-step noise reduction treatments of cab equipped Caterpillar D-9G bulldozer. Note that because this dozer was already equipped with a relatively new muffler, the treatments do not include installation of a new muffler. However, an effective muffler should be part of any noise control treatment if the machine has no muffler as the existing muffler is badly rusted.

TABLE 10. - Summary of material and labor costs for noise control package on International Harvester TD-25C bulldozer with ROPS-FOPS only

Treatment	1978 material costs[2]	Labor[1] Welder	Labor[1] Mechanic	Treatment	1978 material costs[2]	Labor[1] Welder	Labor[1] Mechanic
Windshield.........	$537	8	53	Seat seals, hydraulic box seal......	$150	0.5	7.5
FOPS canopy absorption........	182	1	8	Total.........	912	9.5	70.5
Floormat...........	43	NAp	2	Option: Dashboard barrier seal......	400	NAp	7

NAp Not applicable. [1]Estimated worker-hours. [2]Approximate.

other two bulldozers, the noise reductions achieved with individual treatments on the TD-25C depended on the presence of the other treatments. The windshield and the ROPS-FOPS canopy absorption were the two most important treatments; the others would have been ineffective without them. The dashboard barrier was considered to be an optional treatment because its cost was high compared to the noise reduction resulting from its installation.

Front End Loader (5-6)

The front-end loader ranked second to the bulldozer as a "noise offender" in the surface mining industry (1). Although about 40 pct of the loaders identified during the 1977 census were equipped with factory-designed acoustical cabs; the remaining 60 pct required some type of retrofit noise control treatment. The Bureau chose two of the most popular loader models for the retrofit program--a Caterpillar 988 and an International Harvester H-400 B. Both machines had nonacoustical operator cabs; this made the retrofit treatments easier to install than if they had equipped only with ROPS-FOPS structures.

The treatments themselves were similar to those installed on the cab equipped bulldozer: (1) exhaust mufflers, (2) seals around openings in the cab walls, doors, seats, and floors, and

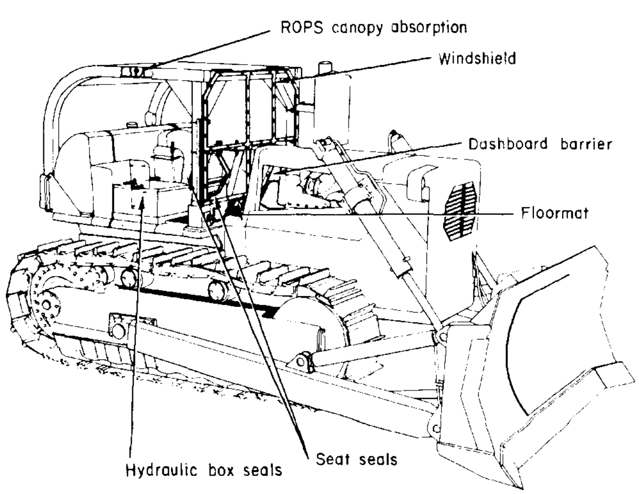

FIGURE 6. - Noise control treatments installed on International Harvester TD-25C bulldozer.

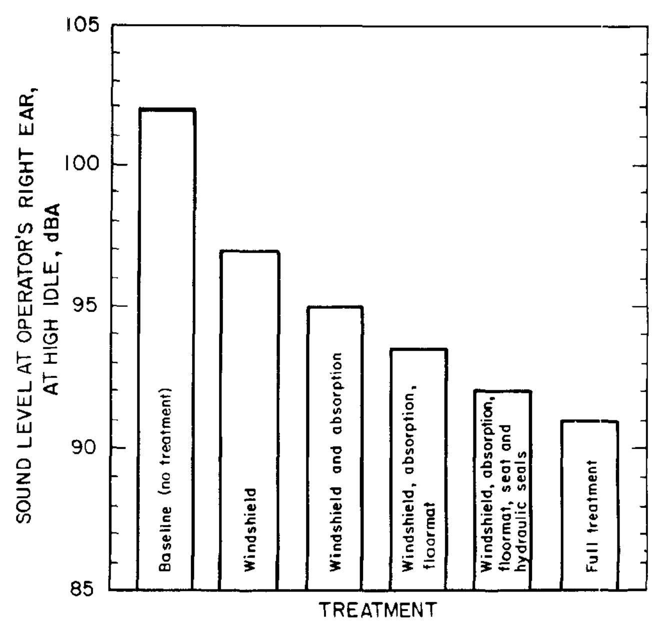

FIGURE 7. - Step-by-step noise reduction treatments of International Harvester TD-25C bulldozer.

(3) sound-absorbing materials on all the interior cab surfaces, including the canopies. Table 11 summarizes the noise reductions, material costs, and labor hours associated with the retrofit treatments. As with the cab-equipped bulldozer, the noise levels in the untreated loader cabs were the same or greater when the doors were closed than when they were open, due to the doors rattling in their sockets. After treatment, however, the loader cabs were quieter when the doors were closed. Note also that the costs of installing exhaust mufflers are not included in table 11 because the loaders already had mufflers. If mufflers had not been present, they would have been essential components of the noise control packages.

Figures 8 and 9 and table 12 describe the retrofit package on the Caterpillar 988 loader; figures 10 and 11 and table 13 do the same for the International H-400 B. As with the bulldozer retrofit packages, the effectiveness of each successive noise control treatment depended on the presence of previous treatments.

TABLE 11. - Summary of results of front-end loader retrofit noise control treatments

	Caterpillar 988	International Harvester H-400 B
Operator noise level, dBA:		
Before treatment.................	[1]99-[2]101	[1,2]95
After treatment..................	[2]90-[1]91	[2]83-[1]87
Noise reduction...............dBA..	[2]11	[2]12
1978 material costs[3]...............	$410	$580
Labor hours.......................	29	19

[1]Cab doors open. [2]Cab doors closed. [3]Not including exhaust muffler.

TABLE 12. - Summary of material and labor costs for noise control package on Caterpillar 988 front-end loader

Treatment	1978 material costs[2]	Labor,[1] mechanic	Treatment	1978 material costs[2]	Labor,[1] mechanic
Canopy wall seals.....	$58	7	Additional sound absorption on cab interior............	$63	5
Canopy and rear cab wall sound absorption	200	8	Total...........	410	29
Floormat..............	39	3			
Pedestal seals........	50	6			

[1]Estimated worker-hours. [2]Approximate.

TABLE 13. - Summary of material and labor costs for noise control package on International Harvester H-400B front-end loader

Treatment	1978 material costs[2]	Labor,[1] mechanic	Treatment	1978 material costs[2]	Labor,[1] mechanic
Cab wall seals........	$138	8	Floormat.............	$49	3
Cab sound absorption..	393	8	Total..........	580	19

[1]Estimated worker-hours. [2]Approximate.

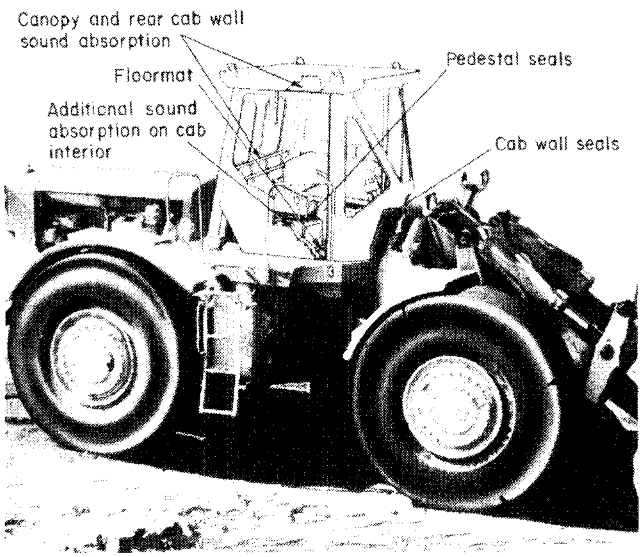

FIGURE 8. - Noise control treatments installed on Caterpillar 988 front-end loader.

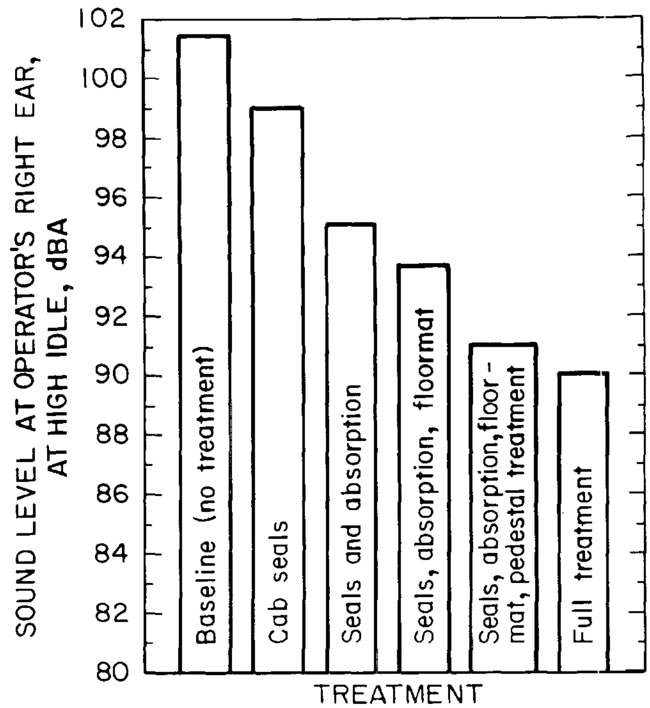

FIGURE 9. - Step-by-step noise reduction treatments of Caterpillar 988 front-end loader.

CONCLUSIONS

The noise exposure of U.S. surface coal miners was evaluated. A 1977 study indicated that over 25,000 mobile machine operators (nearly 45 pct of the approximately 56,200 operators) were overexposed to noise according to the criterion specified in the Federal Coal Mine Health and Safety Act of 1969 and subsequent amendments of 1977.[5]

Heavy track dozers were the largest contributors, responsible for 54 pct of the overexposure, and rubber-tired front-end loaders were second in importance, contributing to 19 pct of the overexposure. On the basis of these results, the Bureau selected bulldozers and front-end loaders for which to develop and prove cost-effective retrofit noise control techniques. Durable cost-effective noise control techniques were proven and well documented, which, in general, provide over 10 dBA of noise reductions at typical costs of $1,000 in materials and 100 h of labor.

[5] It is estimated that for all surface mines (coal and metal and nonmetal) that over 50,000 mobile machine operators are overexposed to noise.

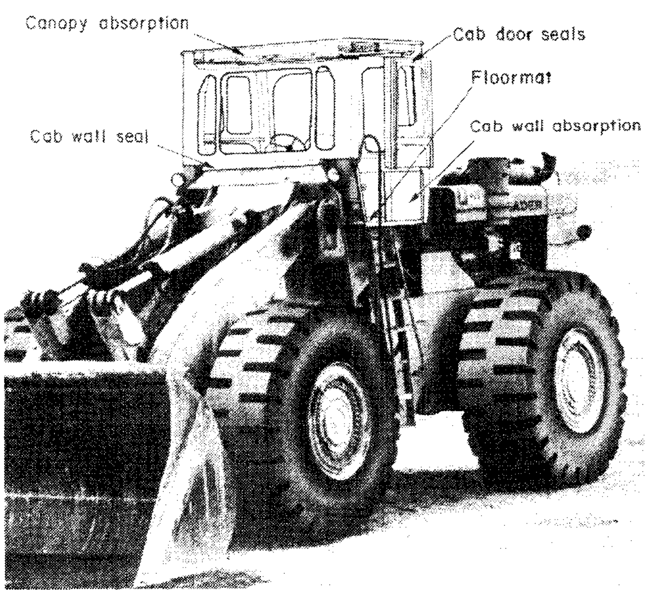

FIGURE 10. - Noise control treatments installed on International Harvester H-400 B front-end loader.

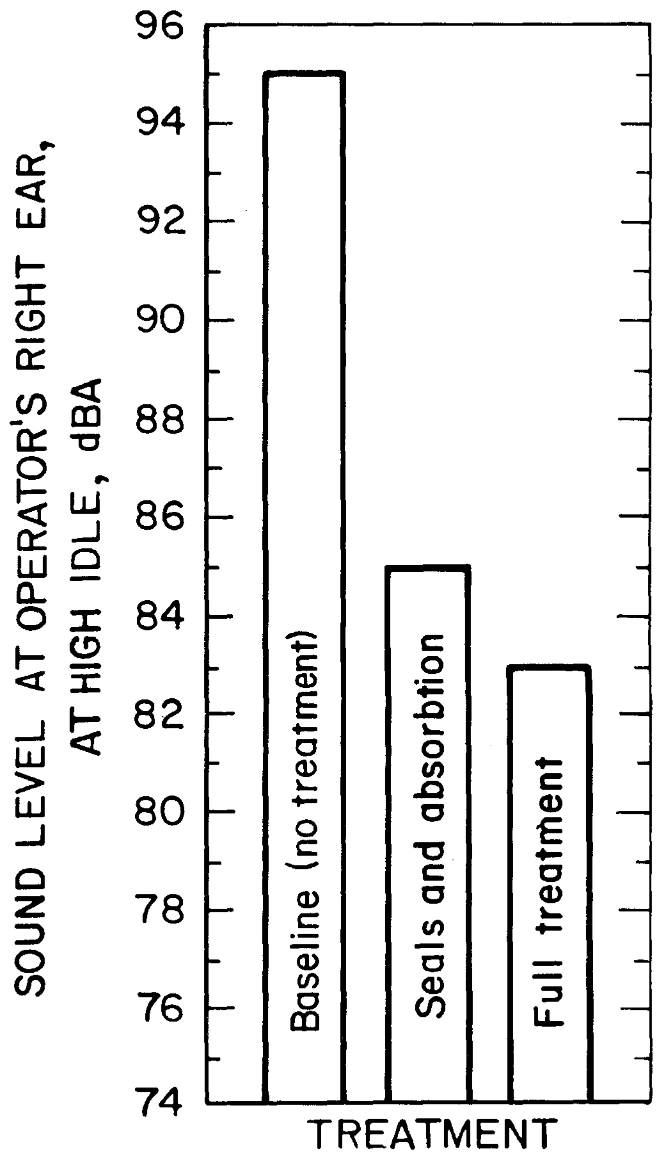

FIGURE 11. - Step-by-step noise reduction treatments of International Harvester.

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APPENDIX A--CALCULATION OF AVERAGE WORKING NOISE LEVEL

The average working noise level is a useful concept for characterizing the noise exposure contribution of a given machine that produces nonconstant noise levels. The average working noise level is defined as the constant noise level that results in the same noise dose as the actual nonconstant noise levels, for the period the machine is operating.

For example, consider a machine that subjects its operator to a 90-dBA noise level while it idles and to a 95-dBA level while it is used at full power; assume also that the machine operates at idle for 30 pct of the time it is in use and at full power 70 pct of the time. Note from table A-1 that the permissible exposure duration for 90 dBA is 8 h and for 95 dBA, 4 h. Assuming a total of 7 h of use per day ($7 \times 0.30 = 2.10$ h at 90 dBA and $7 \times 0.70 = 4.90$ h at 95 dBA), a total noise dose of $2.10/8 + 4.90/4 = 1.487$ is obtained. The average working noise level in this case is that noise level producing a noise dose of 1.487, if it is continuous for 7 h.

The permitted exposure duration, T, in hours is related to the noise dose, D, and actual exposure duration, C, in hours as

$$T = C/D.$$

Thus, here the permitted duration, T, is $7/1.487 = 4.71$ h. From the values indicated in table A-1, one may observe that the average working noise level is between 92 and 95 dBA. The exact value of 93.8 dBA can be calculated from the equation in the note to table A-1.

The assumed value of the daily use time (taken above as 7 h) does not affect the value of the average working noise level. The effects of the assumed values of the daily use time cancel, because the same number is used in the dose evaluation calculation and in the determination of the corresponding permitted durations.

TABLE A-1. - Permissible noise exposures

Duration of exposure per day, h	Noise level, dBA	Duration of exposure per day, h	Noise level, dBA
8	90	1.5	102
6	92	1	105
4	95	0.5	110
3	97	0.25	115
2	100		

NOTE.--Noise levels are measured with a sound level meter set to slow response. Exposure to continuous levels above 115 dBA is not permitted by law. Values between those tabulated may be obtained from $\log T = 6.322 - 0.602$ SL, where T denotes the exposure duration, h, and SL is the sound level, dBA.

Information Circular 8986

Noise Control

Proceedings: Bureau of Mines Technology Transfer Seminars, Pittsburgh, PA, July 24, 1984, and Denver, CO, July 26, 1984

Compiled by Staff, Bureau of Mines

UNITED STATES DEPARTMENT OF THE INTERIOR
William P. Clark, Secretary

BUREAU OF MINES
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Library of Congress Cataloging in Publication Data:

Bureau of Mines Technology Transfer Seminars (1984 : Pittsburgh, PA, and Denver, CO)

Noise control.

(Information circular / United States Department of the Interior, Bureau of Mines ; 8986)

Includes bibliographies.

Supt. of Docs. no.: I 28.27:8986.

1. Noise control–Congresses. 2. Mine safety–Congresses. I. United States. Bureau of Mines. II. Title. III. Series: Information Circular (United States. Bureau of Mines) ; 8986.

TN295.U4 622s [622'.4] 84-600194